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Soft X-ray Emission from Alexandrite Laser-Matter-Interaction

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13. ABSTRACT *(Maximum 200 words)*

X-ray spectroscopy was used to quantify the plasma generated by a focused, Alexandrite laser as a potential alternative source in proximity lithography. An x-ray emission efficiency of 2 - 11% was determined by analysis of spectral data (10 - 14A) from transition-metal targets.

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SOFT X-RAY EMISSION FROM ALEXANDRITE LASER-MATTER-INTERACTION

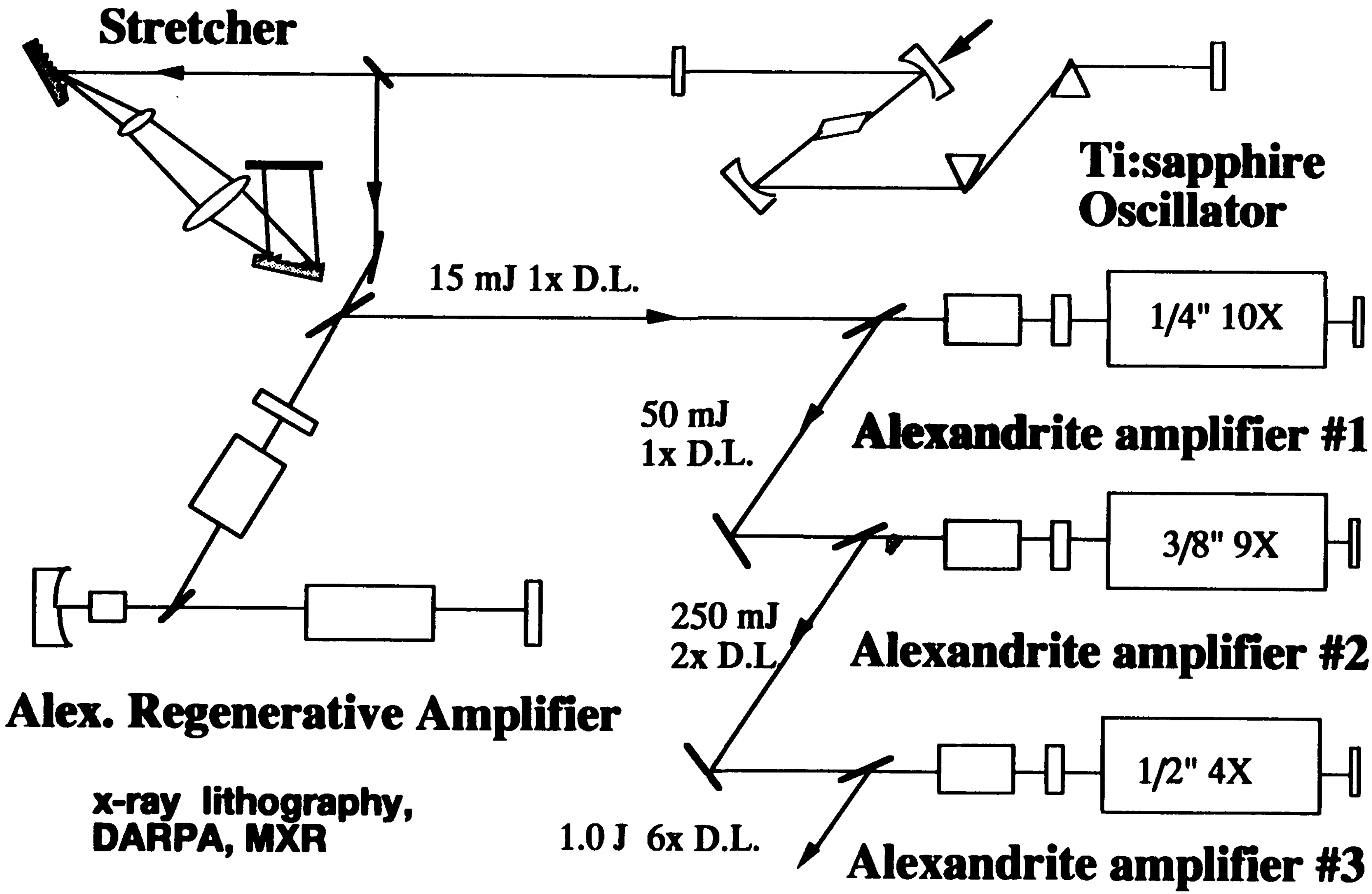
Manuscript approved June 6, 1993.

EXPERIMENTAL

A compact (table-top), focused Alexandrite (750 nm) pulsed-laser system generated soft x-ray emission from planar-metal targets. Quantitative x-ray spectroscopy (active and passive detection) and pinhole imagery were used to characterize the 10 - 14 Å region that is important for resist exposure in proximity x-ray lithography. X-ray data was collected from transition metal targets. The spectra, acquired on film, were densitometered and computer processed to obtain line intensities from the L-shell transitions in highly-ionized copper and iron plasma. Spectral data was also acquired from K-shell transitions in aluminum in order to compare the effects of less than 8 Å spectral wavelengths (>1.5 keV energy) as the more energetic x-rays have greater penetration in the lithographic process.

The 10 Hz Alexandrite laser system at Allied Signal employs a Ti: sapphire oscillator, a pulse-stretcher (grating-pair), and a three-stage Alexandrite regenerative amplifier stage. The laser can generate chirped pulses (0.75 ns) up to 1 joule. These pulses can be recompressed to shorter pulse widths with an additional grating pair. Spectral data was acquired with both single laser pulses and a train of widely-spaced (8-ns) laser pulses.

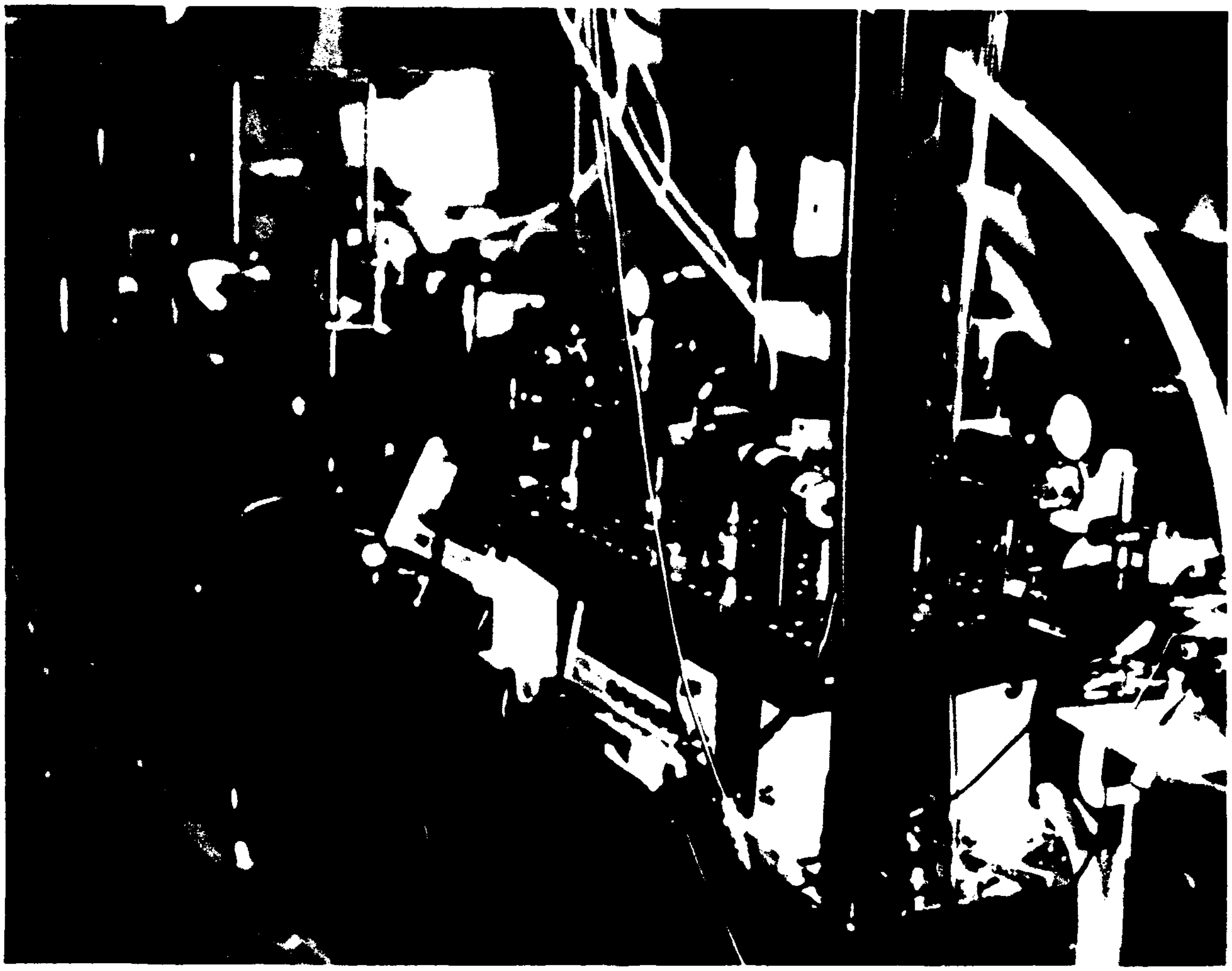
1 Joule, 1 ns, 10 Hz alexandrite laser
5 to 3 amplifiers



ALEXANDRITE FOCUSSED LASER

ALLIED-SIGNAL Corp.
Morristown, NJ

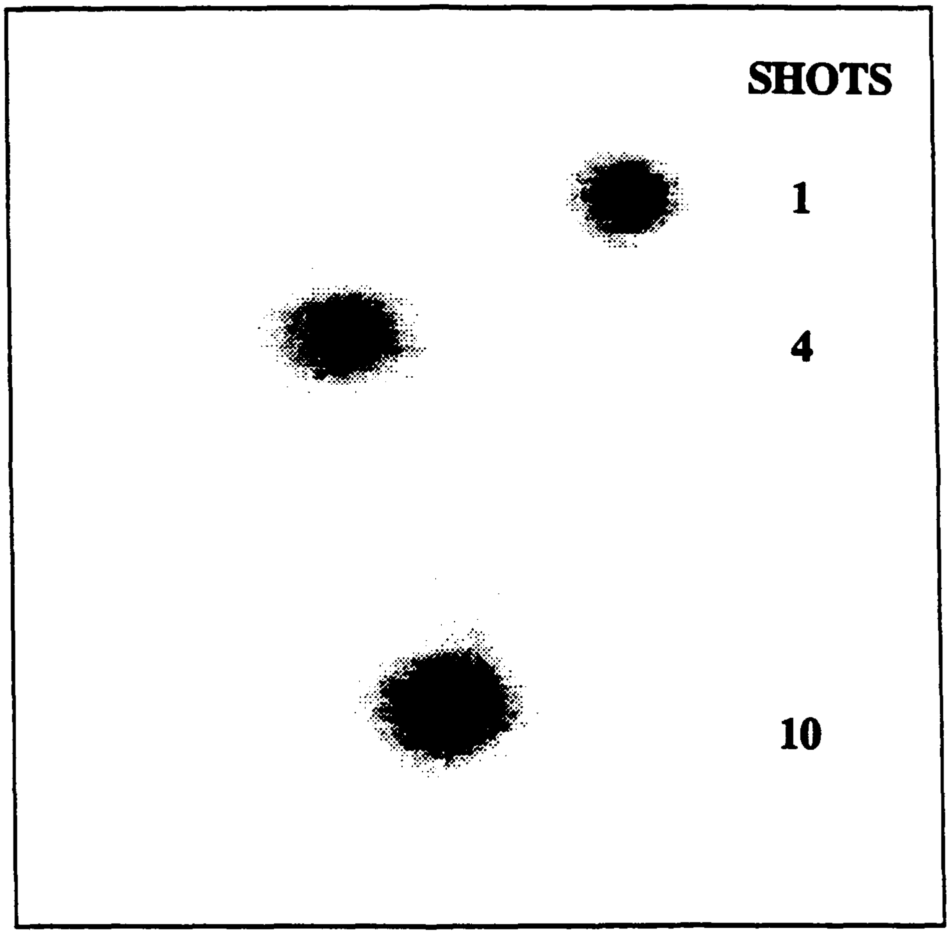
Wavelength:	800 nm
Pulse Energy:	1 J
Pulserwidth:	3/4 ns
Repetition Rate:	10 Hz



X-RAY PINHOLE IMAGES

for

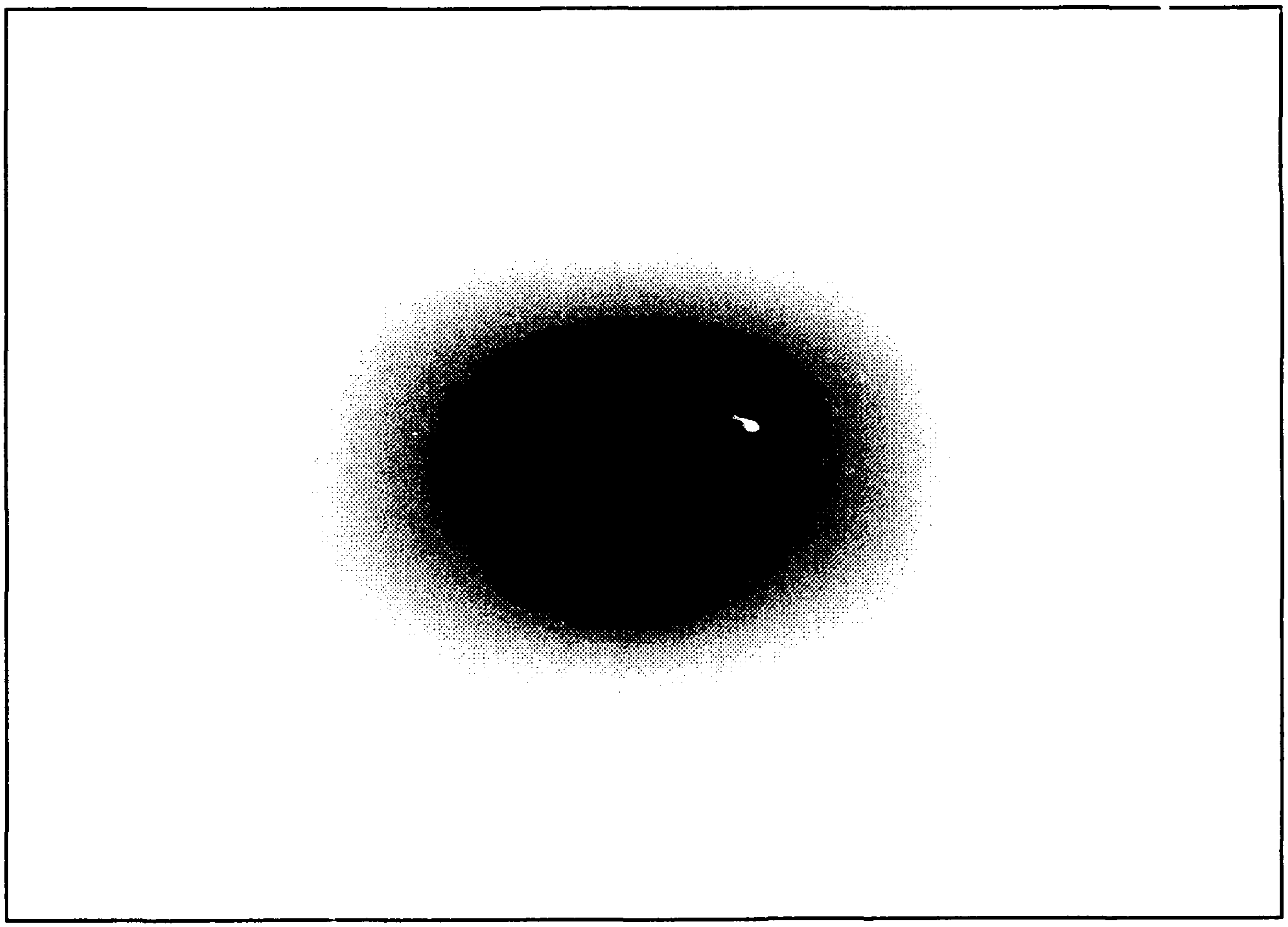
ALEXANDRITE LASER

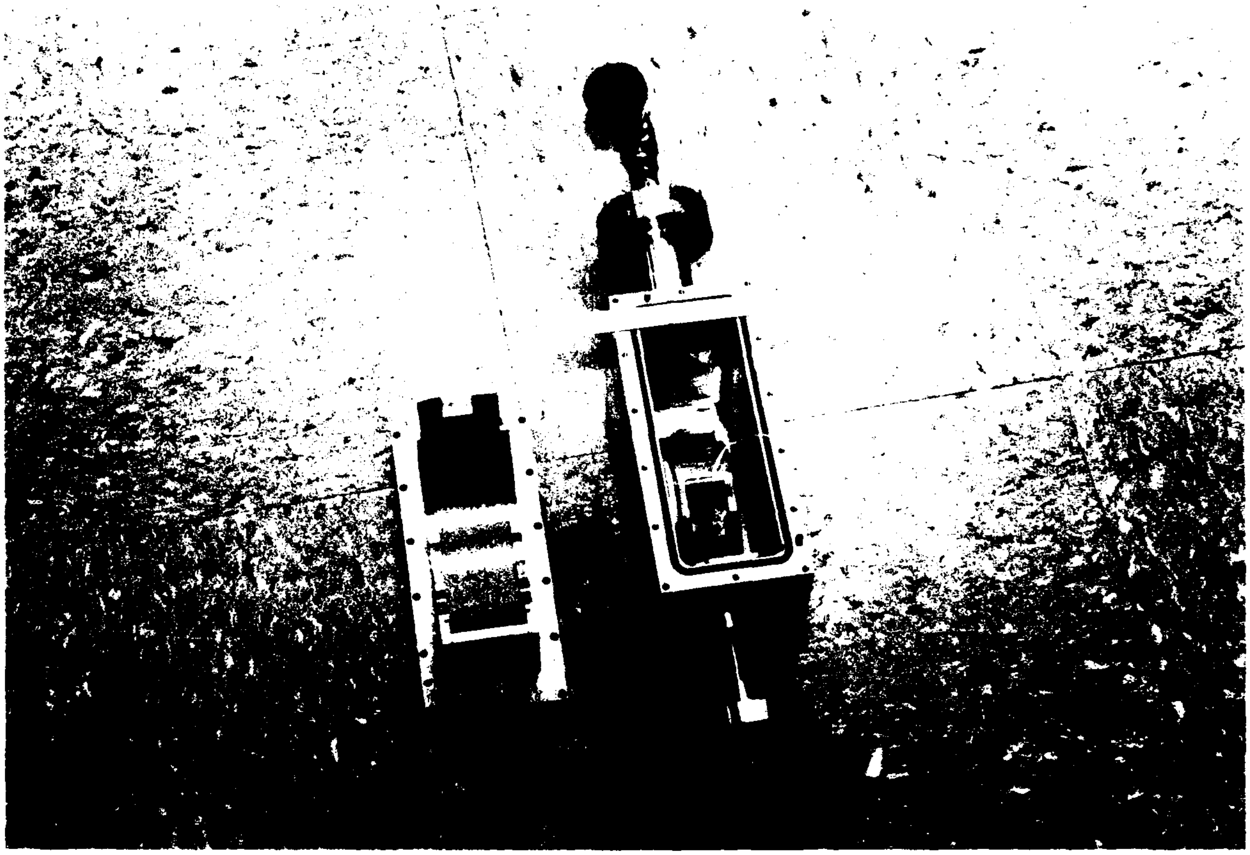

SHOTS
1
4
10

X-RAY EXPOSURE UNIFORMITY

Curved-Channel Plate Array Camera

Allied Signal, Shot 8, 22-Dec-1992

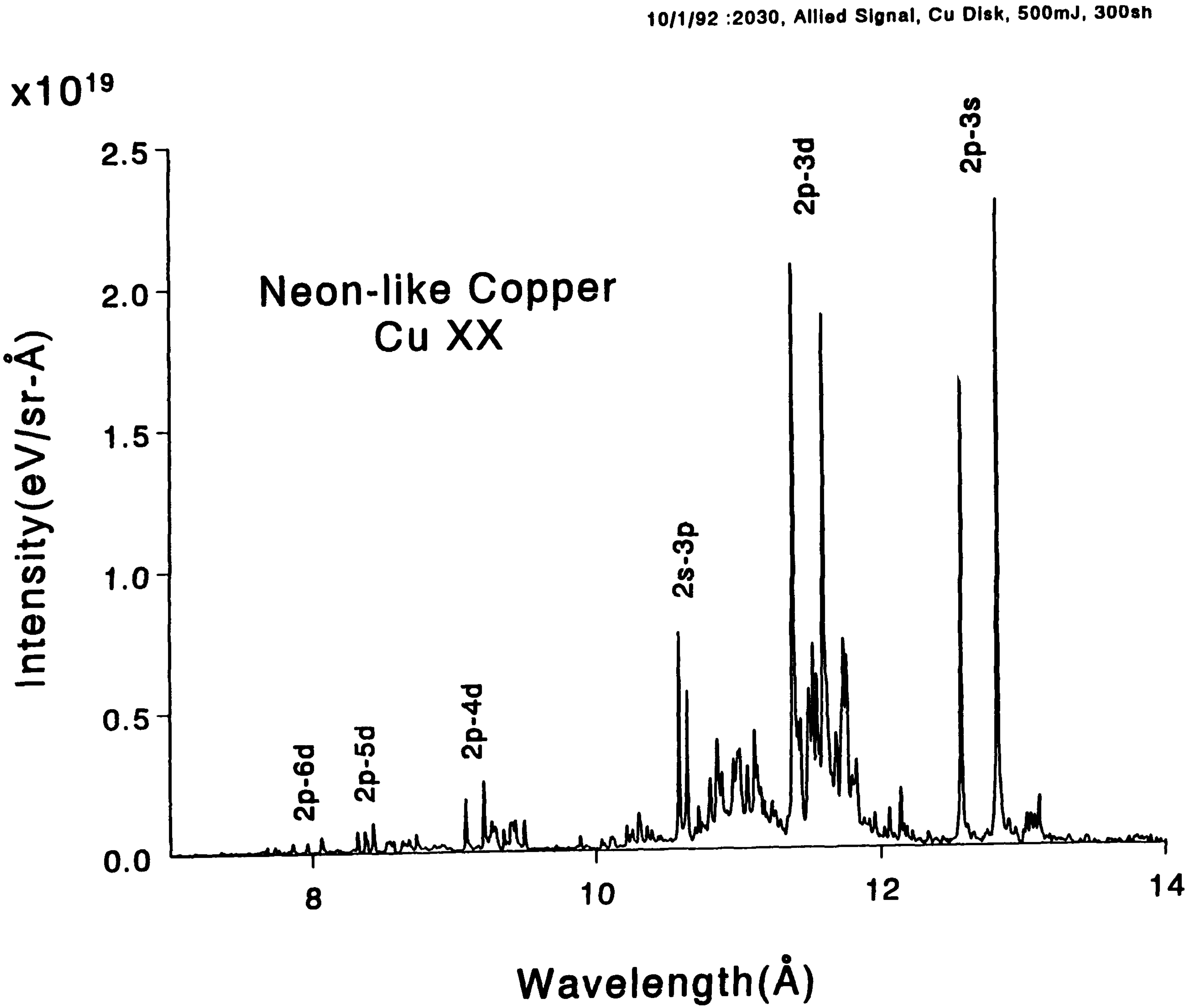


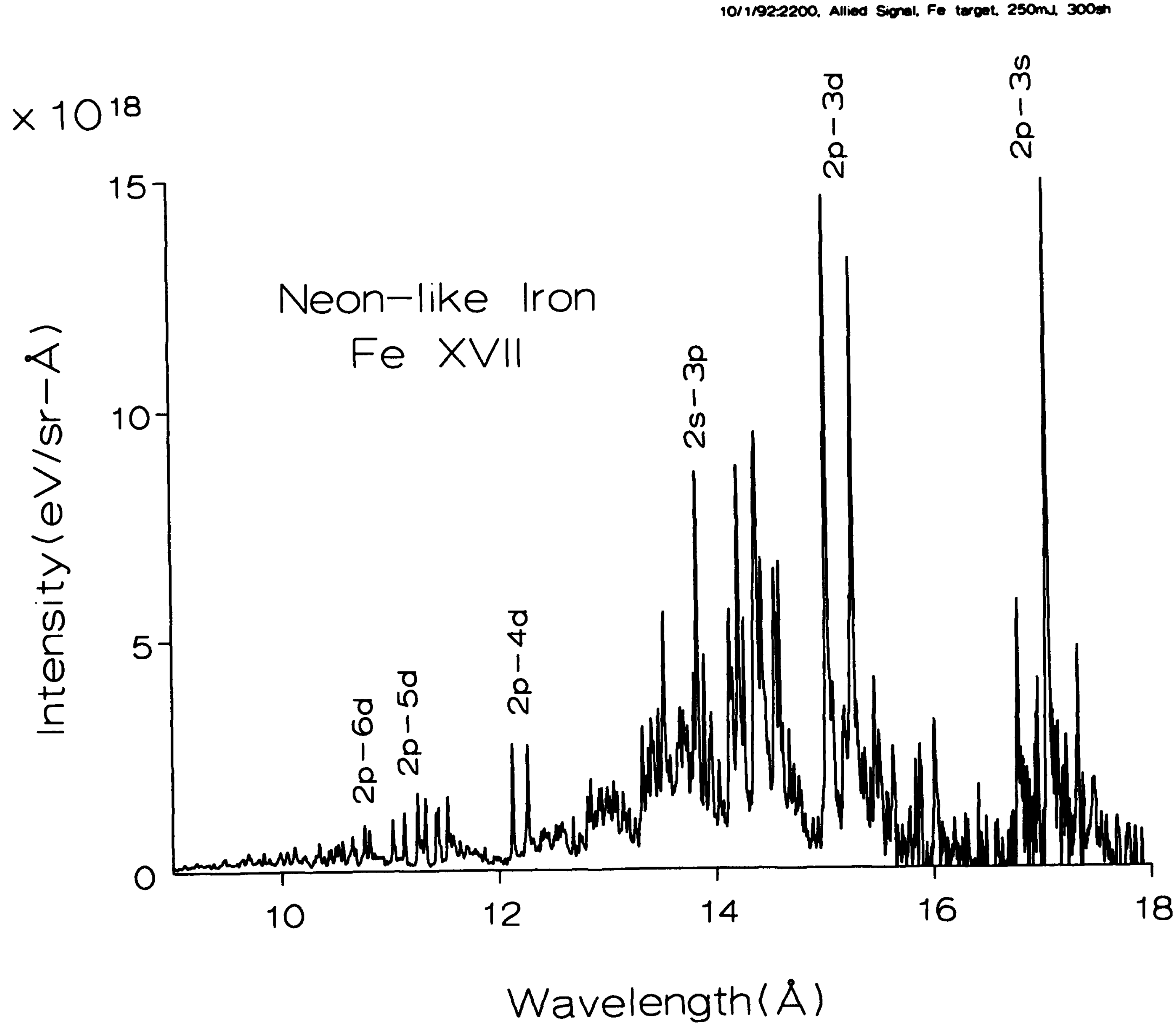


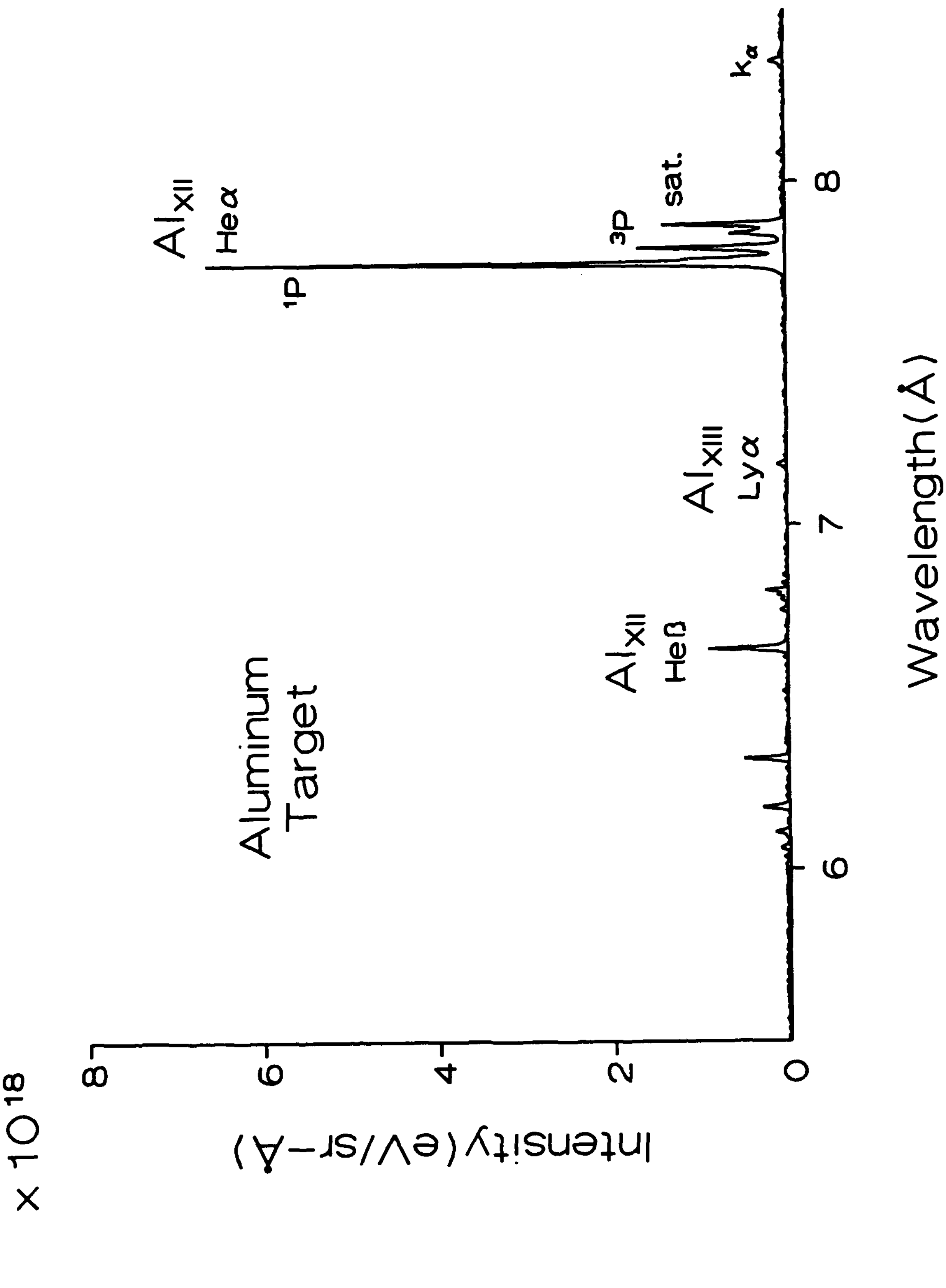
SPECTRA

from

ALEXANDRITE LASER


10/1/92 :2030, Allied Signal, Cu Disk, 500mJ, 300sh
x10^19
Intensity(eV/sr-Å)
2.5
2.0
1.5
1.0
0.5
0.0
Neon-like Copper
Cu XX
2p-6d
2p-5d
2p-4d
2s-3p
2p-3d
2p-3s
8
10
12
14
Wavelength(Å)


10/1/92:2200, Allied Signal, Fe target, 250mJ, 300sh
x 10^18
Intensity(eV/sr-Å)
15
10
5
0
Neon-like Iron
Fe XVII
2p-6d
2p-5d
2p-4d
2s-3p
2p-3d
2p-3s
10
12
14
16
18
Wavelength(Å)



× 10^18
Intensity (eV/sr–Å)
0
2
4
6
8
6
7
8
Wavelength (Å)
Aluminum Target
Al XII Heα
1P
3P
sat.
Kα
Al XIII Lyα
Al XII Heβ

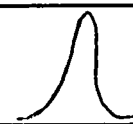
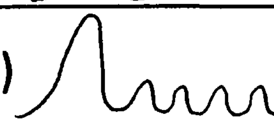
Table I. X-Ray Spectral Intensities Generated by Alexandrite Laser.

Target Material	Shot Sequence	Number of Shots	Spectral Range Angstrom	Integrated Intensity eV/sr	Output Joules into 2π	Output mJ/shot into 2π	η, %
Cu	10/1/92:1400	400	7-14	$1.89 \bullet 10^{18}$	1.9	4.8	1.9
	10/1/92:1500	270	7-14	$3.74 \bullet 10^{18}$	3.8	14.1	2.8
	10/1/92:1630	300	7-14	$3.75 \bullet 10^{18}$	3.8	12.7	2.5
	10/1/92:2030	300	7-14	$4.98 \bullet 10^{18}$	5.0	16.7	3.3
Fe	10/1/92:2130	300	9-18	$7.86 \bullet 10^{18}$	7.9	26.3	5.3
	10/1/92:2200	300	9-18	$8.54 \bullet 10^{18}$	8.6	28.7	11.5

X-RAY SPECTRAL DATA

for LASER PULSE TRAIN

Soft X-Ray Output

Data Group	Energy on Copper Target	Number shots	X-Ray Intensity (eV/sr)	Pulse Shape	Emission Comparison
Oct.	1/2 J	300	$4.8 \cdot 10^{18}$	a) 	unity
Dec.	1 J	120	$1.1 \cdot 10^{18}$	b) 	less by 2x
Dec.	2/5 J	120	$0.46 \cdot 10^{18}$	c) 	less by 4x

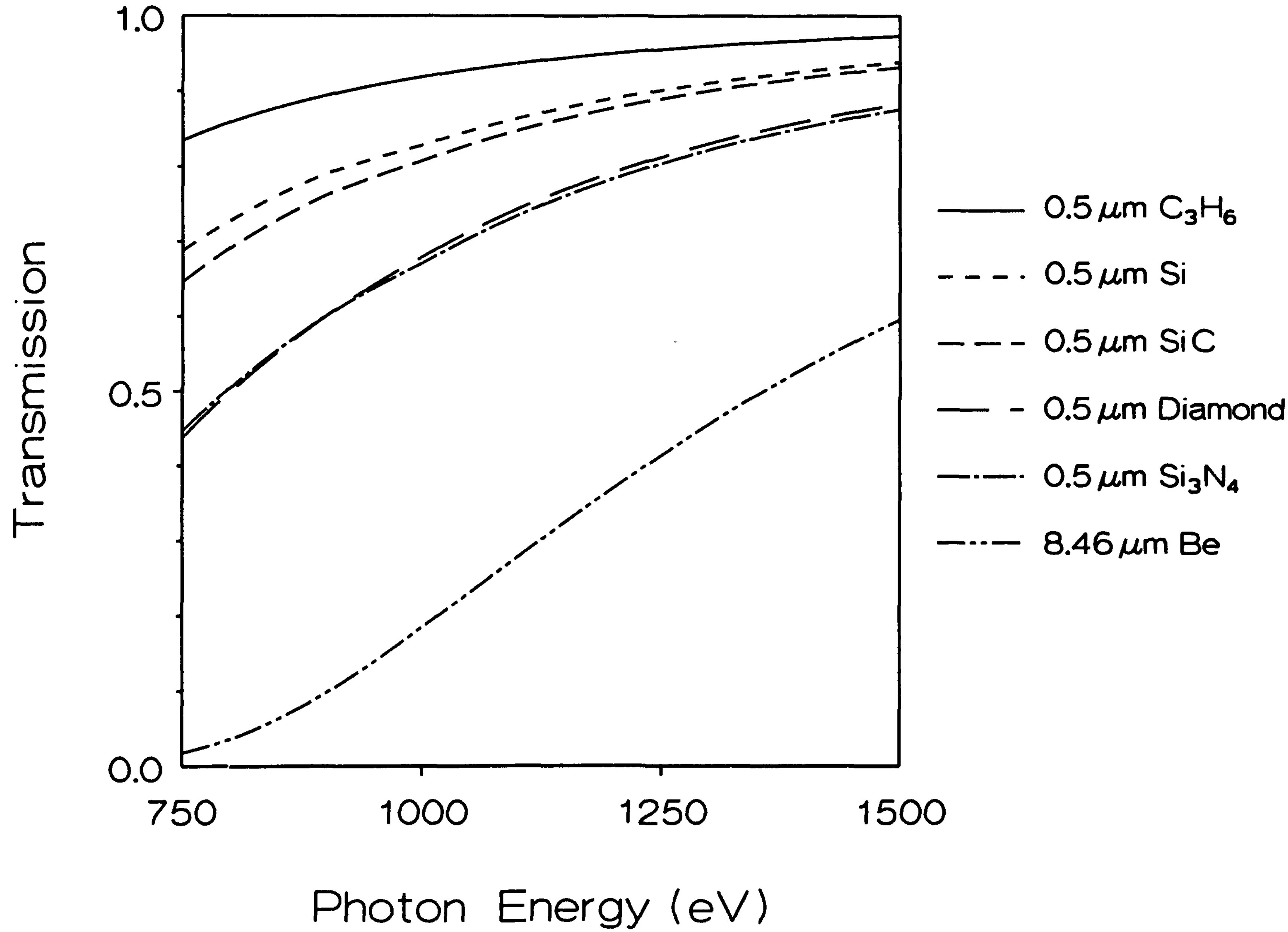
a) single pulse 3/4 ns width
b) train of pulses with 1 J leading edge
c) train of equal-intensity pulses separated by 8 ns

X-RAY SOURCE TRANSMISSION for LITHOGRAPHY

A. X-RAY MASKS + SUBSTRATE

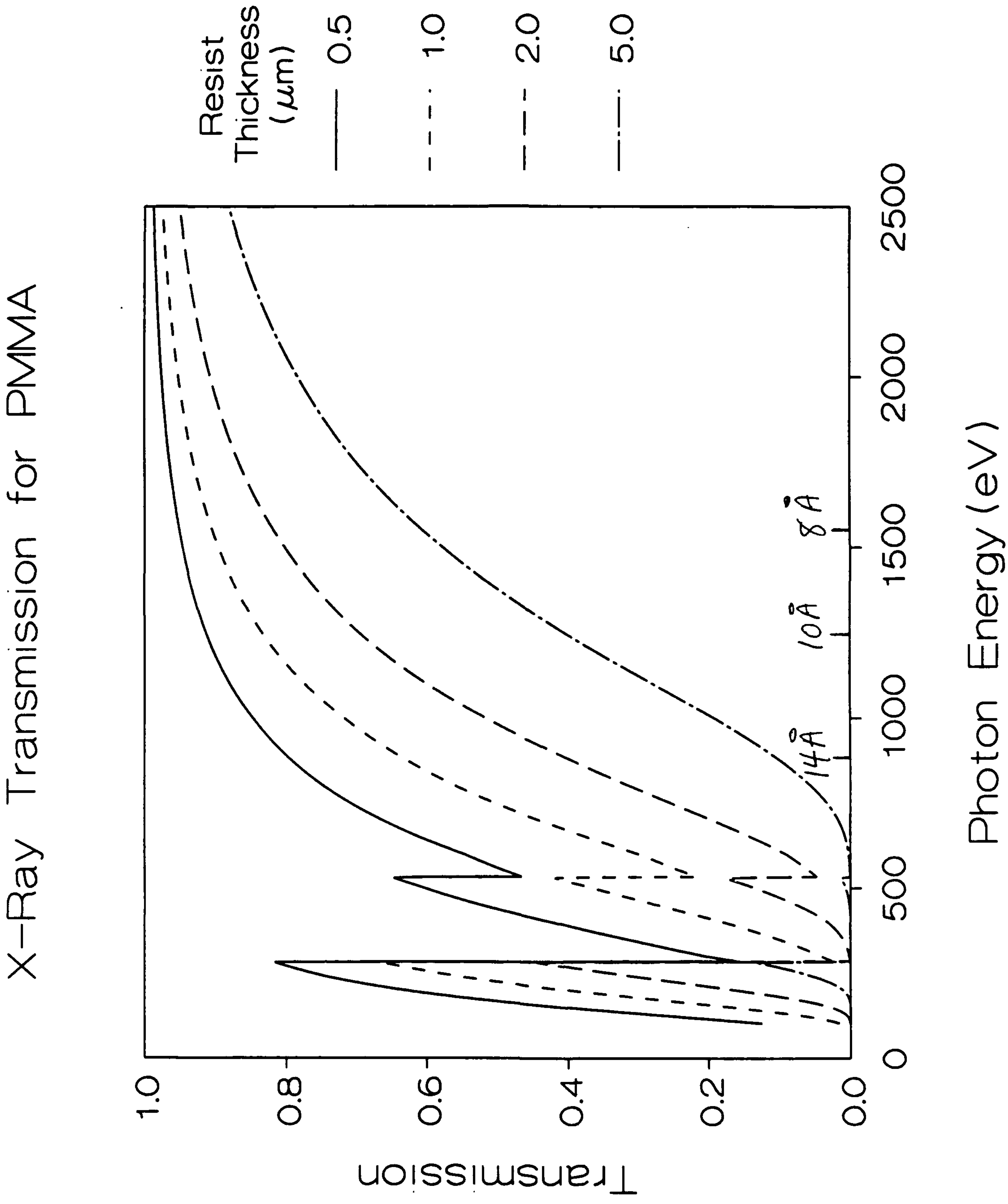
B. X-RAY RESISTS

Transmission of Thin Membranes

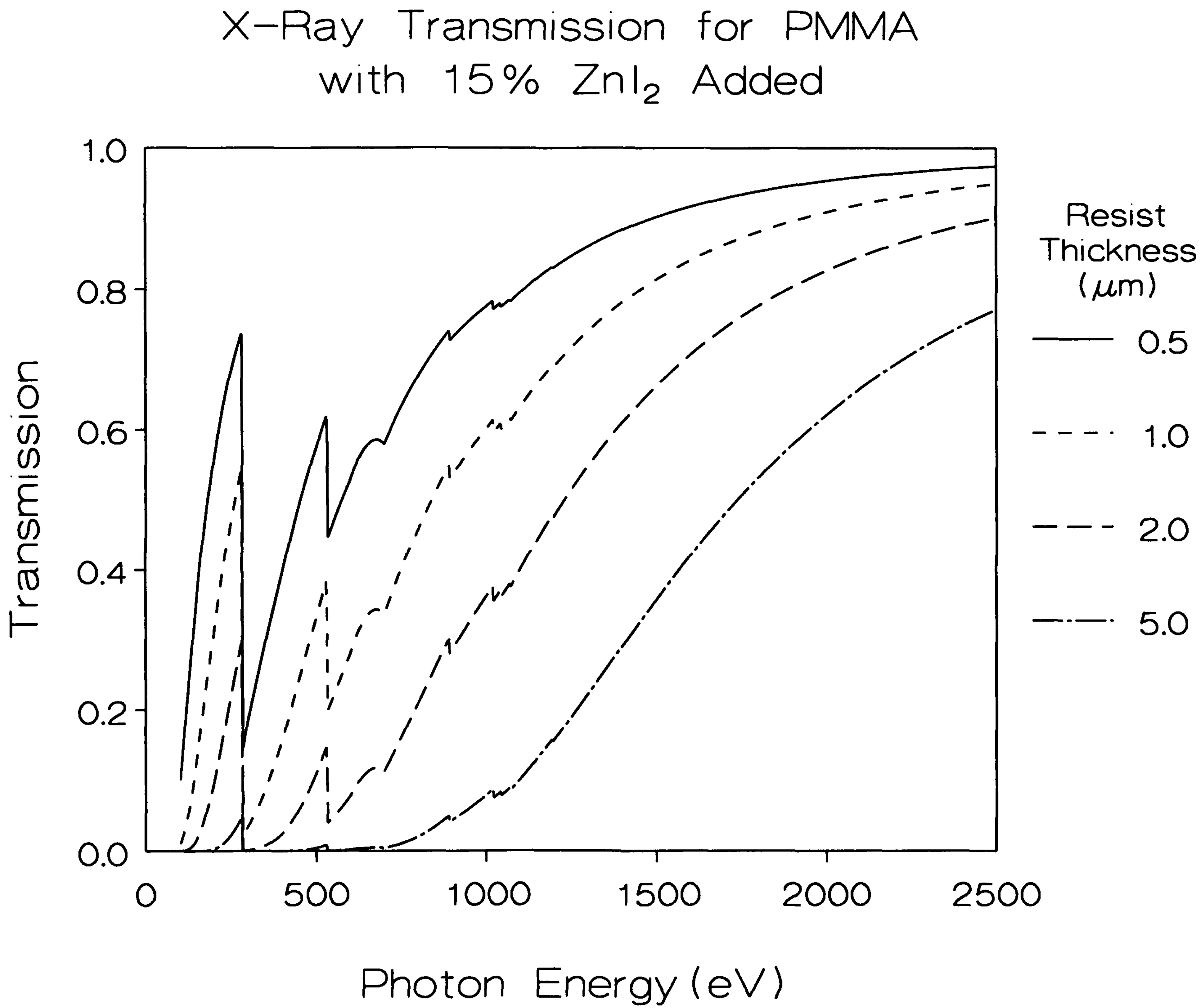


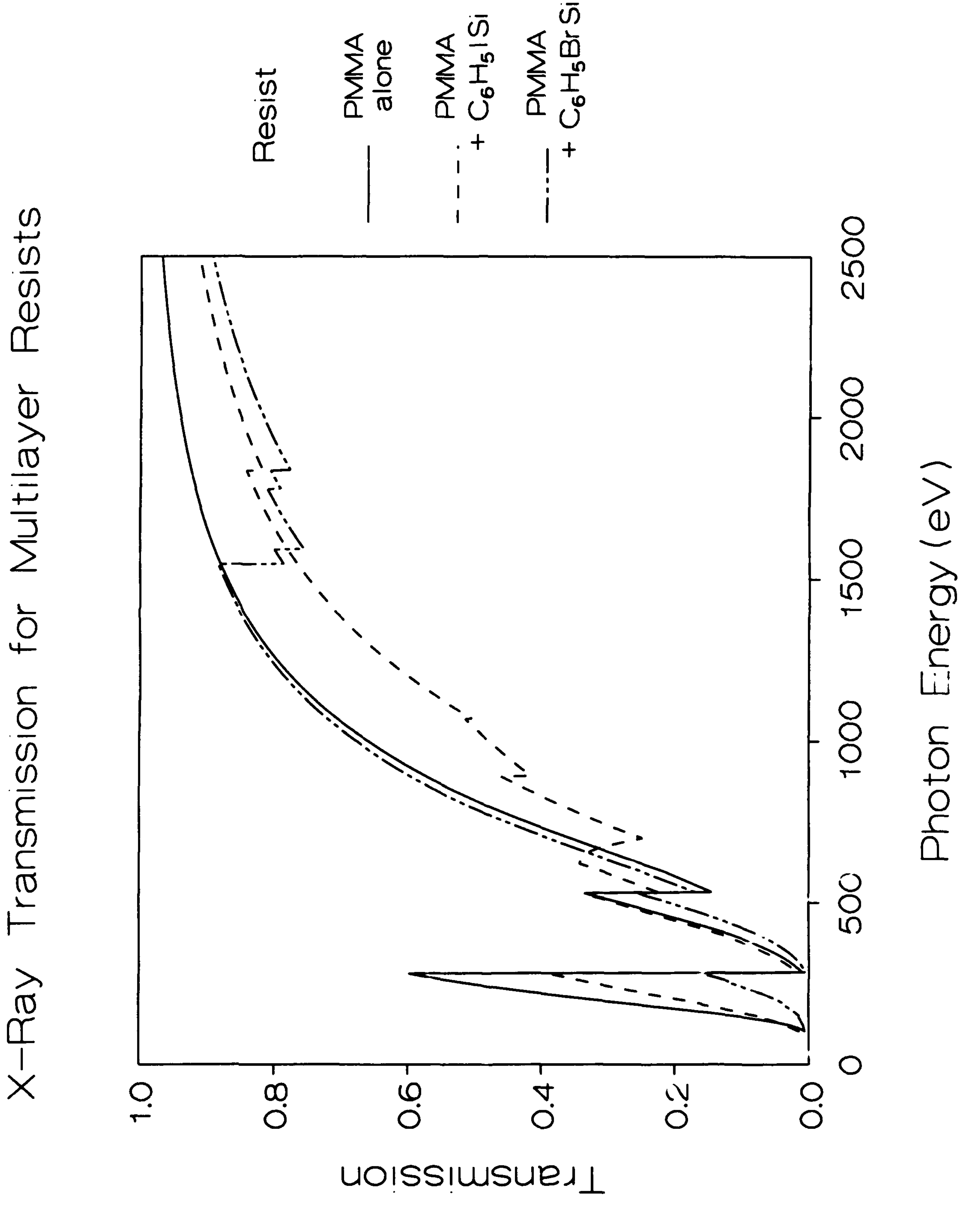
Soft X-Ray Spectral Transmission

Spectrum	Region	Source Strength	Helium Path	Substrate Mask, SiC		Helium Path & Substrate	
	(Å)	(eV/sr)	1atm 20-cm	1-μm	2-μm	1-μm	2-μm
Cu L	7-14	$4.0 \cdot 10^{18}$	84%	63%	40%	53%	33%
Fe L	8-17	$9.9 \cdot 10^{18}$	71%	43%	18%	30%	12%



X-Ray Transmission for PMMA
Transmission
0.0
0.2
0.4
0.6
0.8
1.0
0
500
1000
1500
2000
2500
Photon Energy (eV)
14Å
10Å
8Å
Resist Thickness (μm)
0.5
1.0
2.0
5.0


X-Ray Transmission for PMMA
with 15% ZnI2 Added
Transmission
1.0
0.8
0.6
0.4
0.2
0.0
0
500
1000
1500
2000
2500
Photon Energy (eV)
Resist
Thickness
(μm)
0.5
1.0
2.0
5.0



X-Ray Transmission for Multilayer Resists
Transmission
1.0
0.8
0.6
0.4
0.2
0.0
0
500
1000
1500
2000
2500
Photon Energy (eV)
Resist
PMMA alone
PMMA + C_6H_5ISi
PMMA + C_6H_5BrSi

Table II. Soft X-Ray Transmission.

Target Material	Source Emission (J/sr)	Mask Substrate (J/sr)	Resist PMMA (J/sr)
Aluminum	0.037	0.024	0.022
Copper	0.648	0.415	0.324
Iron	1.411	0.673	0.444

Table III. Soft X-Ray Absorption.

Target Material	Resist Exposure (J/cm^2)	ENERGY ABSORBED IN RESIST: PMMA (J/cm^2)	+15% ZnI (J/cm^2)	Multilayer (J/cm^2)
Aluminum	$6.00 \bullet 10^{-5}$	$4.84 \bullet 10^{-6}$	$8.45 \bullet 10^{-6}$	$1.23 \bullet 10^{-5}$
Copper	$1.04 \bullet 10^{-3}$	$2.29 \bullet 10^{-4}$	$3.63 \bullet 10^{-4}$	$4.67 \bullet 10^{-4}$
Iron	$1.68 \bullet 10^{-3}$	$5.72 \bullet 10^{-4}$	$7.13 \bullet 10^{-4}$	$9.23 \bullet 10^{-4}$

SUMMARY

The diagnostic instrumentation included filtered-PIN diodes, a diffraction-crystal spectrograph, and a film-recording x-ray pinhole camera. The x-ray spectrograph utilized a curved-KAP crystal.

An x-ray spectrum was recorded from a copper target. The most distinct and intense lines originate from transitions to the L-shell in neon-like copper. Spectral lines occur in the 8 - 14 Å region; however, the strongest lines are 2 - 3 level transitions in the 10 - 14 Å range from fluorine-like Cu XXI and Neon-like Cu XX. For the iron data, the same spectral transitions as in copper are generated but are shifted 3 - 4 Å to longer wavelength.

The x-ray output energy was determined assuming uniform emission over 2 π for the plasma generated at the surface of the planar targets. The soft x-ray conversion efficiency of the focused-laser beam was found to range from 1.9% at ¼ J to 3.2% at ½ J integrated over the 10 - 14 Å spectral region with an average efficiency of 2.5% for both copper and iron plasma. The total x-ray emission read in the 7 - 18 Å region is stronger for the iron targets by a factor of 3 because of the intense emission between 14 and 18 Å in neon-like Fe XVII. A soft x-ray conversion efficiency of greater than 10% was recorded for a ½ J iron target shot.

CONCLUSIONS

- **SOURCE STRENGTH**

  Alexandrite laser yields highest efficiency from iron target (L-spectrum) and lowest from aluminum (K-spectrum); however, copper has good L-shell spectral output in the 10 - 14 Å region.

- **LITHOGRAPHIC CONSIDERATIONS**

  Soft X-ray spectral transmission and absorption calculations revealed that the energy deposition into high-Z loaded PMMA resists can achieve greater than 45% soft x-ray deposition for copper and iron L-spectrum but only 20% for the energetic aluminum spectral distribution